Inconclusive Experiments to Determine Whether Skimming Flow Influences Mussel Growth Rates

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Inconclusive Experiments to Determine whether Skimming Flow Influences Mussel Growth Rates

by

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ABSTRACT

Wildish, D.J., Kristmanson, D.D., Akagi, H.M., and Zemlak , T. 2001. Inconclusive experiments to determine whether skimming flow influences mussel growth rates. Can. Manuscr. Rep. Fish. Aquat. Sci. 2581: iii + 35 p.

Flume profiling experiments in an annular flume above a simulated bed of horse mussels show that at 26 adult mussels m^{-2}, skimming flow was absent. By contrast, at 132 mussels m^{-2}, skimming flow was present, as indicated by reduction of flow of up to 50% in the spaces between the roughness elements. Two populations of the horse mussel, *Modiolus modiolus*, were used in field experiments at one location in Passamaquoddy Bay. Our purpose was to test the null hypothesis that skimming flow does not affect the feeding and growth of horse mussels. The field experiments were compromised, and therefore considered inconclusive, because the tidal vanes did not operate properly and serious fouling occurred on all parts of them. Horse mussel growth rates from the field experiment were low and variable, including negative growth in some cases, with significant mortalities. Reductions in condition factor in both control and experimental horse mussels were found, which supports the contention that factors other than skimming flow hydrodynamics were dominant in this particular experiment. A more controlled flume experiment with blue mussels, *Mytilus edulis*, was devised to test the same skimming flow hypothesis. The flume was supplied with unfiltered seawater from the main SABS supply line. These results were also inconclusive, as indicated by the low growth rate in control mussels caused either by the low seston concentration in the unfiltered seawater supply or physiological insufficiency of the mussels.

RÉSUMÉ

Wildish, D.J., Kristmanson, D.D., Akagi, H.M., and Zemlak , T. 2001. Inconclusive experiments to determine whether skimming flow influences mussel growth rates. Can. Manuscr. Rep. Fish. Aquat. Sci. 2581: iii + 35 p.

Des expériences de profilage dans un canal rotatif au-dessus d'un gisement simulé de modioles indiquent qu'il n'y a pas de flux d'écrémage à une concentration de 26 modioles adultes/m^{-2}. En revanche, à une concentration de 132 modioles/m^{-2}, le flux d'écrémage se produit comme l'indique la réduction allant jusqu'à 50 % du flux dans les espaces entre les rugosités. Deux populations de modioles, *Modiolus modiolus*, ont été utilisées dans les expériences sur le terrain réalisées à un endroit dans la baie Passamaquoddy. Notre expérience avait pour but de mettre à l'essai l'hypothèse de différence nulle selon laquelle le flux d'écrémage n'influe ni sur l'alimentation ni sur la croissance des modioles. Les expériences sur le terrain ont été compromises et sont donc considérées non concluantes, car les vannes à marée n'ont pas bien fonctionné et il y a eu considérablement de salissures sur les tous les organismes. Les taux de croissance des modioles dans les expériences sur le terrain ont été faibles et variables et, dans certains cas, il y a même eu une croissance négative et un taux de mortalité assez important. Des réductions dans le coefficient de condition ont été observées tant chez le groupe témoin que chez le groupe expérimental des modioles, ce qui accrédite l'hypothèse que des facteurs autres que l'hydrodynamique du flux d'écrémage ont dominé dans cette expérience en particulier. Une expérience davantage contrôlée en canal portant sur les moules bleues, *Mytilus edulis*, a été mise au point pour vérifier cette même hypothèse sur le flux d'écrémage. Le canal a été alimenté d'eau de mer non filtrée provenant de la principale ligne d'approvisionnement de la Station biologique de St. Andrews. Ces résultats ont également été non concluants, comme l'indique le faible taux de croissance des moules témoins attribuable au très faible taux de concentration du seston dans l'approvisionnement en eau de mer non filtrée.

INTRODUCTION

Benthic boundary layer flow on the Continental Shelf includes both hydrodynamically smooth (=laminar) and rough (=turbulent) conditions, although the typical case is the latter. Turbulent flows interact with the substrate, which may have biogenic (e.g. epibenthic macrofauna, tubes) or geological (e.g. sand ripples, cobbles) protuberances, termed roughness elements. The size and spacing of roughness elements is of importance in determining the flow pattern that results. Skimming flow conditions are created when the roughness elements reach a critical density. At and beyond critical densities, the roughness elements are so close together that the flow is deflected to a plane above the roughness elements. The flow within aggregated roughness elements is slower and poorly mixed in comparison with interacting wake or isolated element flow, which occur in the turbulent flows at lower roughness element densities (Morris 1955).

Previous studies have recognized skimming flow conditions in field studies of epibenthic horse mussels in New Zealand (Green et al. 1998), although this was not related to biological effects, and in polychaete tube mats (e.g. Frederichs et al. 2000), where sediment stabilizing and substrate conditioning, allowing further benthic succession, were recognized.

Not only biogenic roughness elements, but surficial geological features must be considered as interacting with flow if we are to fully understand all of the factors that control suspension feeding, and thus growth and production in benthic suspension feeders. The purpose of this study was to examine the hypothesis that the poor growth of horse mussels, *Modiolus modiolus*, living on cobble substrates in the Bay of Fundy (Wildish et al. 1998), could be explained by limitation of seston supply due to skimming flow. The rationale for our point of view is given below.

If we assume that cobbles are 10-cm diameter spheres (d), or larger, and that they are distributed over the bottom area in a regular grid pattern so that the centre-to-centre distance, D, between each roughness element is constant, then, using the roughness density estimate of Nowell and Church (1979), skimming flow is likely when:

$$N A_e/A_t \geq 1/12 \qquad (1)$$

where N = density of roughness elements defined as numbers per m^2, A_e = plan area of individual roughness element, and A_t = total area occupied by roughness elements. With d = 10 cm, we calculate that D≤30.7 cm if skimming flow is present.

Boundary layer conditions over a cobble substrate are hydrodynamically rough at current speeds of greater than a few cm s^{-1} and, if the density and size of cobbles is sufficient to induce skimming flow, we predict that seston supply in the interstices between cobbles will be limited. This results because of:

- slower mechanical transport of seston from the bulk flow across the shear zone near the top of the roughness elements; and
- the high potential for seston depletion by bivalves in the slowly circulating eddies between the roughness elements.

In a previous theoretical treatment of the turbulent supply of seston to populations of active suspension feeders (Wildish and Kristmanson 1979), we recognized three possible bulk seston concentration ranges (C) in relation to the concentration in seawater just sufficient to meet the maintenance growth requirements of the suspension-feeder population (C^1). These were:

1. where $C > C^1$ and no mass transfer limitation was likely
2. where $C^1 \cong 0.2\text{-}0.8\ C$ and turbulent mass transfer rates may reduce the density of suspension feeders that can be supported
3. where $C^1 > C$ and seston levels are insufficient to support a population of suspension feeders.

Considering the second case above, under skimming flow conditions, a concentration deficit between bulk seston concentration and that close to the suspension feeder is established and maintains convective/ diffusive transport towards the animal. Seston is "consumed" in the near-bed layer, both by animal consumption and sedimentation processes. Skimming flow conditions set a slower transfer rate across the sheared zone than occurs under wake interference and isolated element flow conditions (Fig. 1). Hence, where skimming flow and high densities of active suspension feeders are present, seston depletion is more likely to occur than in other types of rough turbulent flow.

The null hypothesis we attempted to test was that, under skimming flow, mussels grow at the same rate as those in turbulent interacting wake or isolated element flow conditions.

MATERIALS AND METHODS

HORSE MUSSELS USED IN EXPERIMENTS

Mussels from two contrasting populations were used in growth experiments to determine skimming flow effects - from Sandy Point and Mathew Cove.

The Sandy Point mussels (Fig. 2) were found on a substrate consisting of cobbles, with occasional larger rocks and a sandy sediment between the cobbles. They occurred, usually singly, wedged between the cobbles and partly buried in the sand. This habitat was only exposed at LWS and received ebb-flow runoff throughout the spring tide LW period. This is the same habitat and horse mussel population studied by Rowell (1967).

The Mathew Cove mussels (Fig. 2) occurred in a pool at about mid-tide level, with typical depths of 0.5 m. The pool received trapped ebb-flow runoff when not submerged. The mussels were attached directly to the rock of the pool bottom and some of them were covered with the encrusting red alga *Lithothamnion* sp. They occurred at quite high densities, one 1-m^2 quadrat count yielding 136 mussels. Other green, brown and red macroalgae were also present on the tidal pool floor.

The mussels were maintained in flowing water holding tanks of 1-m diameter at ambient seawater temperatures. We used the unfiltered seawater supply at SABS. The tank water was also recirculated by means of a small submersible pump.

On subsamples of each population, we measured the same biometric characters as in Wildish et al. (1998). These included valve length, valve dry weight, tissue wet and dry weight and sex (by gonad color). To compare the growth characteristics of the two populations, we also calculated condition factor (see p. 7, equation 5), regressed valve length on total weight and determined age by growth ring increments in the first 4 yr of life as in Wildish et al. (1998)

BLUE MUSSELS USED IN EXPERIMENTS

In a second series of experiments we used blue mussels. They grow faster and are more tolerant of culture than horse mussels. Consequently, we obtained 100 sexually immature mussels from the Great Eastern Mussel Farms, Tenants Harbor, Maine. The mussels were harvested on June 28, 2001 and shipped by road to Calais, where they were retrieved on June 29 and placed in a holding tank at SABS by 1130 h.

ANNULAR FLUME EXPERIMENTS

In order to demonstrate that dense beds of horse mussels would create skimming flow, we undertook flow-profiling experiments in an annular flume (Fig. 3). The setup conditions for the flume are shown in Table 1. Local, filtered seawater of ~30 PSU was piped into the flume and flow induced, in a counter-clockwise direction, by paddles. The gap between the flume floor and the bottom of each paddle was 12.5 cm on the inside and 15 cm on the outside channel wall. Flow measurements were made with a specially designed, L-shaped, series 403 Streamflo probe, manufactured by Nixon Instrumentation, Cheltenham, Gloucestershire, UK, GL53 8DZ. The probe rotor, made of PVC, was 11 mm in diameter and protected by a metal ring so that the closest the rotor tip came to the flume floor was 2.5 mm. The probe shaft was bent at right angles so that it extended 15 cm into the flume channel mid-point. Flow profiling was undertaken at two locations, A (upstream of the model mussels) and B, as shown in Fig. 3 and 10. The flow probe was placed as close to the flume floor as the metal ring would allow, supported on a metal post attached to the outer channel wall, followed by incremental moves of 1 cm upwards as marked on the post. The probe was positioned where the middle, model mussel should have been, approximately 8.5 cm downstream of the mussel in the preceding row (Fig. 10).

The roughness elements used in flow profiling experiments were model horse mussels. The models were prepared by filling shucked, paired horse mussel valves with marine cement. The 50 valves used were selected from those available after processing the horse mussels to obtain the data shown in Appendices 1 and 2. Mean valve measurements of the models are shown in Table 1. Using Velcro on their sides, model mussels were attached to a mussel plate cut from 5-mm thick Plexiglas, so that the posterior of the mussel was facing into the flow. The plate was cut to just fit into a 1.25-m long section of the annular flume channel. The plate had a bevelled upstream edge to deflect flow. At the highest density, there were five model mussels (Fig. 10b) in each row (6 cm apart at the mussel mid-point), with a total of 10 rows (each 12.5 cm apart at the mussel mid-point). The roughness height of the model mussel bed could be determined from the mean valve width of all the model mussels (see Table 1).

Ten consecutive readings, in hertz (Hz), were recorded from the Streamflo digital meter at each height above the flume floor. Means of each one were then converted from hertz to cm s^{-1} (y) by

$$y = 2.2769\ Hz - 14.804,\ R^2=0.99 \qquad (2)$$

from a calibration made with an independent acoustic flow meter. Flow profiles were compared graphically with height above the flume floor (y) on velocity, converted to percentages of control flows, without roughness elements (x). Individual mean velocities at different heights from the flume floor were also compared by t-test.

FIELD EXPERIMENTS

The experiments were based on horse mussel growth on tidal vane deployments in which the leading edge of the vane always faced into the flow. The tidal vane deployment system was originally developed for holding gypsum cylinders into the flow and is fully described in Wildish et al. (2000). Each deployment consisted of a pair of anchoring concrete blocks joined by a lead line. One of the blocks was connected by a line to a bladder buoy for retrieval, and the other block to a short line and smaller submerged buoy to carry the metal frame and swivel. The vanes, made of Plexiglas and 45 x 60 cm in dimensions, were ~2-3 m above bottom when deployed. A total of eight tidal vanes were deployed to be as close as possible to each other at Tongue Shoal, Passamaquoddy Bay (Fig. 2).

The roughness elements used in the field experiments were wooden dowels of 3.5 cm diameter (the largest locally available) that were cut to 4.5-cm lengths. The dowels were firmly fixed to one side only of the vane by brass screws. They were arranged on the vane surface so that the mid-point distance between each dowel was the same (range 7-9 cm apart, depending on density). The dowels simulated small cobbles or horse mussels of these dimensions.

Five live horse mussels, which had been measured for valve length and total wet weight on the day before deployment, were attached with bathtub adhesive into specially made adaptors on the downstream edge of each vane (Fig. 4). Both smooth (control) and rough surfaces had five mussels positioned so that their posterior ends faced the flow. Each mussel could be individually identified after gluing a small, numbered tag into a dried part of the valve prior to deployment. The mussels used in the field experiments came either from Sandy Point or Mathew Cove. At the termination of the experiment, we again measured valve length and total wet weight. In addition, all of these mussels were sacrificed and biometric measurements, inclusive of soft tissue dry weights as described in Wildish et al. (1998), completed.

Growth was calculated as in Wildish et al. (1987), that is, as percentage weight or length adjusted daily biomass per day

$$[W_1-W_0/W_0N] \times 100 \qquad (3)$$

where N = time in days, W_0 = initial weight, g, and W_1 = final weight, g, or as specific daily valve length growth:

$$[L_1-L_0/L_0N] \times 100 \qquad (4)$$

where L_0 = initial length, mm, and L_1 = final length, mm. We also calculated the condition factor, CF, from Brock and Wolowicz (1994) as:

$$CF = (W_1/V) \times 100 \qquad (5)$$

Where W_1 is dry tissue weight and V is the total weight of both valves.

FLOW-THROUGH FLUME EXPERIMENTS

The outside flume at SABS (Wildish 1991) was used. It was set up at the top of the shore, protected by a shed, and supplied with unfiltered seawater taken from the SABS main seawater intake line before filtration. The flume was modified for our experiments as shown in Fig. 5 so that two equal channels - control and experimental - were available. Seawater was delivered to the flume in two 3-in. pipes to a common source.

The working section of the flume was 5 m in length and live mussels were placed in five rows, beginning at the 3.0-m mark and thereafter at 25-cm intervals downstream in both channels. In the experimental channel, the same model horse mussels as used in the annular flume experiment were placed in rows of five between the live mussels and in six rows upstream of the first live blue mussels. Both live and model mussels were attached by Velcro strips glued to the floor, and small pieces of Velcro glued to the right side of the valve with Super Glue. Model and live mussels were placed in rows 12.5 cm apart and 6 cm apart (at the mid-point) with the rows as in the annular flume experiment and, hence, reproduced the highest density of 132 mussels m^{-2}. At the beginning of the experiment, all mussels were

laid on their right sides so the posterior end faced the oncoming flow.

Continuous measurement of temperature was made with a Stow Away Tidbit (Anset Computer Corp., Bourne, MA, USA), placed at the entrance to the working section. Seston concentration, as chlorophyll a, was measured on one occasion at the termination of the experiment, by standard fluorometric method, with calibration against Sigma chlorophyll a. Flow profiling in the flume was with a straight 403 Stream Flo probe (#1330) at locations denoted by distances in metres along the flume working section. Growth was calculated exactly as for horse mussels (equations (3), (4) and (5)).

METHODS FOR PREDICTING SKIMMING FLOW CONDITIONS

Two methods were used to predict whether skimming flow might be expected in defined roughness conditions.

The already-mentioned roughness density, RD, estimate of Nowell and Church (1979) depends on the total surface area of the mussel plate, divided into the sum of the planar areas occupied by each roughness element (Table 2). For model mussels, the planar area, PA, was determined as the elipse:

$$PA_{mussel} = \pi \text{ (valve length x height/2)} \quad (6)$$

The planar areas of dowel cut surfaces were determined as:

$$PA_{dowel} = \pi r^2 \quad (7)$$

when RD $\geq$0.0833, skimming flow is expected (Nowell and Church 1979).

The areal concentration of roughness elements, λ, method of Green et al. (1998) was estimated as:

$$\lambda = kh/D^2 \quad (8)$$

where model mussel valve width is k and valve height, h. D is the distance apart between the mid-point of each mussel (Table 3) as in the roughness density estimate. For dowels, the height is k and h the diameter. When $\lambda \geq 0.2$, skimming flow is expected (Green et al. 1998).

RESULTS

HORSE MUSSEL POPULATION ANALYSIS

Our experience with reading growth rings in horse mussels (Wildish et al. 1998) suggests that it is difficult to achieve and probably is not a very accurate indication of growth. For the Mathew Cove mussels, it was only possible to measure linear increments at age for the first 4 yr and results are shown in Table 4. They suggest that newly settled spat grow slightly faster initially in the calm conditions of the tidal pool at Mathew Cove. However, by the age 3 year-class, both populations are growing at the same rate.

Biometric data for the two populations appear in Appendices 1 and 2, and are summarized in Fig. 6-8. Regression analysis suggests that the growth rates are initially higher at Mathew Cove, with high CFs at smaller sizes (Fig. 8). But the condition factor rapidly declines with size at Mathew Cove, possibly related to intraspecific competition for seston supply as size increases. By contrast, the Sandy Point mussels have a much flatter inverse slope relationship between size and CF, which we interpret to be caused by an adequate seston supply, less intraspecific competition and stress due to water movement (important in early growth stages). We see in Fig. 7 that both populations follow the same general trend in the relationship between dry weight on valve length. We suggest that some individuals from Mathew Cove are growth inhibited due to competition for sestonic food. Horse mussels at Sandy Point also grow to a larger size than at Mathew Cove, and this probably involves differences in age between the two populations, although this cannot be determined definitively from growth ring analysis.

LABORATORY DEMONSTRATION OF SKIMMING FLOW

The temporal persistence of velocity measurements was determined over a period of 240 min (not shown). The results suggest that at speed setting 7 on the motor driving the paddles (~22 cm s^{-1} bulk velocity), and at Z=0.8 cm, the velocity readings are stable over time. Velocities measured at A and B in the flume (with mussel plate present but no mussels) suggest that the sheared layer is of 2-3 cm in height (Fig. 9). At higher velocities in the flume, speed settings 8 and 10 (~26-39 cm s^{-1}), the height of the sheared layer increases to 4-5 cm (not shown).

Effect of density

Two densities were tested as shown in Tables 2 and 3, with the mussels distributed as shown in Fig. 10. Velocity profiles at the lower density and two bulk velocities (Fig. 11) show that no skimming flow is induced in these conditions. By contrast, at the higher density of roughness elements and at two velocities (Fig. 12), skimming flow does occur. This is demonstrated by the significantly lower relative flows at Z <5-7 cm when a high density of model mussels is present. Reductions in velocity at levels below the roughness element height range up to 25-50% of the controls without roughness elements present.

Effect of number of rows

The above results at the highest density were obtained with 10 rows of mussels, and we wished to test the sensitivity of our results to the numbers of rows of model mussels present. Consequently, we repeated the flow profiling at two velocities after first removing three rows (seven rows) and then five rows (five rows). The results (Fig. 13) show no change in effect when measured at location B.

FIELD EXPERIMENTS

A summary of the horse mussels retrieved at the termination of the growth experiment is shown in Table 5. The growth experiments were started on July 14, 2000. They were observed on two occasions by hauling a few of the frames on August 4 and October 5. On the first occasion, there was no evidence of fouling, but on the second, much of the ropes, plastic surfaces of the tidal vanes, wooden dowels and live mussels were covered with fouling organisms. The dominant organisms included ascidians and foliose coelenterates, which added considerably to the weight and caused buckling of the frames during hauling. The fouling resulted in mussel overgrowth and competition with ascidians and other suspension feeders for suspended food. In some cases, the ropes of the mooring system also appeared to have become tangled during deployment.

Because of the obvious fouling problem, the experiment was terminated prematurely on October 5. Not all of the five live mussels on each roughness side (A) and control side (B) were retrieved as is shown in Table 5. It is presumed that the missing mussels either died or became detached from the frame and sank to the bottom.

The results as final valve length, tissue dry weight and total valve weight for the 83-d long growth experiment are shown in Appendix 3.

We have calculated the weight-adjusted daily growth in wet weight by equation (3) and in valve length by equation (4). The calculated growth rates remove initial size as a variable in comparing individual growth rates. We have combined the Sandy Point and Mathew Cove mussels, assuming that they grow at the same rate, in an attempt to boost the numbers compared (Table 6) by t-test (not shown).

Growth rate differences either for valve length or total wet weight are not different between groups of mussels exposed either to skimming flow (7/ + 8/ in Table 6) or near-skimming flow (9/ in Table 6) conditions. The high variability in the results, with some growing negatively and others being lost to the experiment (by death or escapement), are reflected in the high variances associated with our data (Table 6).

We also calculated the CF for each mussel in the experiment according to equation (5). The results (Appendix 3) suggest that the CF of experimental mussels at the termination of the experiment is much lower than natural stocks (Table 7), which were kept in a laboratory for only a short period (Appendices 1 and 2). It is of interest that both control and experimental mussels had low CF (Table 7) and that the means of both groups were not different from each other by t-test. Compared with natural populations of horse mussel from the two locations shown in Table 7, the experimental mussels have significantly lower CF. The high variance around the mean for the Mathew Cove population is suggestive of a seston depletion:density interaction.

BLUE MUSSEL FLUME EXPERIMENTS

Seawater temperatures increased throughout the experiment, from ~10-11°C to 12-13°C at its termination (Appendix 4). There was evidence of tidal patterns in the temperature record with maxima at LW, tidal variation of a few degrees, and minima at HW. Flow profiling was undertaken on one occasion (Appendix 5A) and suggested flow patterns similar to those in the empty annular flume (control), and with a density of 132 model mussels m^{-2} (experimental), although the depth of water (8-10 cm) was less in the flow-through flume. Weekly observations at a number of points along the flume in each channel (Appendix 5B) suggested that flow was marginally greater in the control ($\bar{x}$ = 8.48 ± SD = 1.08 cm s^{-1}) versus the experimental ($\bar{x}$ = 6.31 ± SD =

0.26 cm s^{-1}) channel measured at 2.0 into the flume and at 6.8 cm above bottom.

Because previous growth experiments with giant scallops, *Placopecten magellanicus*, had suggested that SABS unfiltered seawater carried ample natural seston for growth (Wildish et al. 1992), we monitored only once for chlorophyll a and obtained a very low value (3 μg L^{-1}).

Before the blue mussel flume experiment was begun, 25 individual mussels were sacrificed and biometry completed on them (Appendix 6). From the relationship between valve length and dry weight for this sample, we could predict the initial dry weight of control and experimental mussels. The complete data, including predicted values, are shown in Appendices 7 and 8. The salient feature is that there is little growth in either control or experimental mussels. The mean values ± 1 SD were:

Measure	Control	Experimental	N
Dry weight-Equation (3)	+0.00088±0.00448	-0.00041±0.00427	25
Valve length-Equation (4)	0.01778±0.02911	0.00567±0.00529	25
Condition factor-Equation (5)	10.40±1.72	9.76±1.56	25

We interpret the very small average growth in dry weight and valve length of control mussels as a food (=seston) limitation, unconnected with the aims of this experiment. The control results suggest that the seston available throughout the 41-d experiment was only sufficient to maintain condition (hence, approximately equal to maintenance rations). Thus, the initial condition factor of the mussels measured on June 28, 2001 (see Appendix 6) was 10.33±2.35 - not significantly different from the values shown above. Although the experimental results appear to be in the expected direction, e.g. negative dry weight growth, the inadvertent use of an impoverished seston supply, the differences in growth would be expected to be too small to test the null hypothesis.

DISCUSSION

It proved possible by flume profiling experiments over a simulated bed of horse mussels to show that skimming flow could be created in an annular flume. Thus, at a density of 132 horse mussels m^{-2}, skimming flow conditions above the mussel bed were demonstrated by flow reductions of up to 50% in the sheared layer. At a mean lower density of 26 adult mussels m^{-2}, skimming flow was absent.

The primary purpose of our experiments was to test the null hypothesis that skimming flow over a bed of horse mussels did not reduce the growth rate of living mussels, due essentially to limitations of seston supply between the roughness elements. It is unusual to record inconclusive experiments, but this is what is done here. Our purpose in doing so is to demonstrate that in some types of "ecological" experiments it is often difficult to ensure that seasonal environmental variables are successfully reproduced in field experiments. The blue mussel control experiment is of value in making this difficulty clear either with regard to the food value of the seawater used or physiological responses of the mussels. In the horse mussel field experiment, two unforeseen environmental phenomena involving malfunction of the tidal vanes and fouling on all deployment surfaces caused severe reductions in growth rate and CF of both control and treatment horse mussels. The reduction in growth and CF of both experimental and control mussels is consistent with this interpretation. The blue mussel flume experiment was also inconclusive, probably because of low seston chlorophyll a levels in the unfiltered seawater supply at SABS. Before this experiment is repeated, it needs to be determined whether this is due to fouling in the seawater lines, to an endemic problem caused by the new seawater intake that is positioned at greater depth in the St. Croix estuary, or to some other, as yet unrecognized, problem affecting seston quality and concentration.

We conclude that our results do not provide a test of the null hypothesis and that definitive experiments to do this remain for the future.

ACKNOWLEDGMENTS

We wish to thank the Captain and crew of the PANDALUS III for skillful help in deploying and retrieving the experiments, and Mr. J. Hunt of Mascarene for showing us where to find the Mathew Cove mussels. We thank Mr. Carter Newell of Great Eastern Mussel Farms for providing the blue mussels.

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Table 1. Annular flume setup for simulating skimming flow.

Dimensions	Meters
Diameter to mid-channel	1.95
Channel length at the mid-point	6.10
Channel internal width	0.30
Channel height	0.25
Mid-channel length of both mussel plates	1.25
Distance between A and B	1.57
Flume propulsion, 7 paddles, each	0.24 x 0.10-0.125

Flow characteristics	Units
Flume volume at Z_{max}	~450 L
Z_{max}	0.23 m
U_{max}	~0.45 m s^{-1}
δ, thickness of sheared layer	2-3 cm
U_*	5-6 cm

Model mussels (cm)	N	$\bar{x} \pm 1$ standard deviation
Valve length	50	7.6411 ± 1.003
Valve height	50	4.1983 ± 0.531
Valve width	50	3.0013 ± 0.385

Table 2. Annular flume and field experiment estimates of roughness by the method of Nowell and Church (1979). Flume plate = 0.38 m^2, field plate = 0.23 m^2, $RD_{critical} \geq 0.08$-0.13.

Number per plate	Calculated density, m^2	Valve length, cm	Valve height, cm	Planar area, PA, per plate	RD
ANNULAR FLUME					
50	132	7.64	4.20	0.08	0.21
10	26	7.64	4.20	0.02	0.05
FIELD EXPERIMENT DEPLOYMENT					
0	0	Model radius, cm			
25	109	1.75		0.02	0.09
26	113	1.75		0.03	0.13
30	131	1.75		0.03	0.13

Table 3. Annular flume and field roughness estimates by method of Green et al. (1998); $\lambda = KD/D^2$, $\lambda_{crit.} \geq 0.2$.

ANNULAR FLUME					
Model plus (live) mussels per plate	Density, number m^2	k, cm valve width	h, cm valve height	D, cm	λ
50 (0)	132	3.013	4.1983	6-12.5	0.35-0.08
10 (0)	26	3.013	4.1983	24	0.02
FIELD					
		k, cm model height	h, cm model diameter		
0 (5)	-	-	-	-	-
25 (5)	109	4.5	3.5	9	0.19
26 (5)	113	4.5	3.5	8	0.25
30 (5)	131	4.5	3.5	7	0.32

Table 4. Mean valve lengths in mm at age for two populations of *Modiolus modiolus*.

	Mathew Cove		Sandy Point	
Age	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	N
1	13.45 ± 1.90	22	11.79 ± 3.43	29
2	8.71 ± 1.74	21	7.98 ± 1.40	29
3	8.47 ± 1.35	19	8.30 ± 1.94	27
4	8.77 ± 1.17	13	8.42 ± 3.31	18

Table 5. Summary of horse mussels retrieved in field growth experiments at Tongue Shoal between July 14 and October 5, 2000. Source of mussels: I = Sandy Point, II = Mathew Cove.

Experiment number	Position deployed		Roughness side		Control side	
	N	W	Model mussels	Live mussels	Model mussels	Live mussels
0/I	45 03.748	67 00.532	0	3	0	4
0/II	45 03.721	67 00.530	0	2	0	0
9/I	45 03.764	67 00.450	25	5	0	5
9/II	45 03.754	67 00.437	25	3	0	3
8/I	45 03.790	67 00.392	26	3	0	4
8/II	45 03.773	67 00.390	26	3	0	5
7/I	45 03.804	67 00.348	30	3	0	4
7/II	45 03.815	67 00.348	30	3	0	2

Table 6. Comparison of specific growth rates in horse mussels from Sandy Point and Mathew Cove, combined, at Tongue Shoal in suspended culture for a period of 83 d, beginning on July 14, 2000.

		Valve $(L_1-L_0/L_0N) \times 100$		Wet weight $(W_1-W_0/W_0N) \times 100$	
Mussels	Statistic	A	B	A	B
9/I+II	x	0.0065	0.0127	0.0318	0.0484
	±1 S.D.	0.0082	0.0140	0.0207	0.0272
	N	8	8	8	8
7/I+II + 8/I+II	x	0.0063	0.0058	0.0199	0.0219
	±1 S.D.	0.0058	0.0061	0.0197	0.0418
	N	12	16	12	15
0/I+II	x	-	0.0166	-	0.0422
	±1 S.D.	-	0.0119	-	0.0169
	N	-	9	-	9

Table 7. Comparison of condition factor, CF, estimates within the field experiments and for two naturally growing populations of horse mussel.

Mussels	Treatment	Mean CF ± 1 S.D.	N
Experimental	Control mussels on vanes	8.60 ± 1.90	9
	Roughness side mussels on vanes	6.61 ± 1.54	20
	Control side mussels on vanes	6.64 ± 1.87	23
Natural population	Sandy Point	11.23 ± 1.88	37
	Mathew Cove	18.65 ± 5.59	30

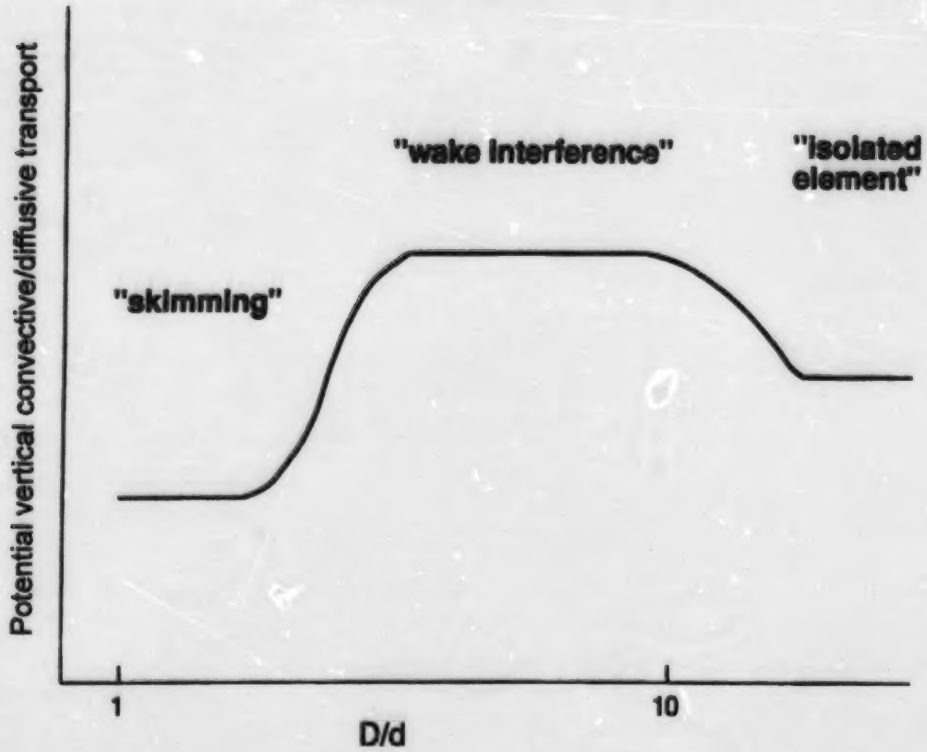


Fig. 1. Diagram of the dependence of vertical convective/diffusive transport in rough turbulent flow defined by element spacing as a ratio of element diameter (D/d).

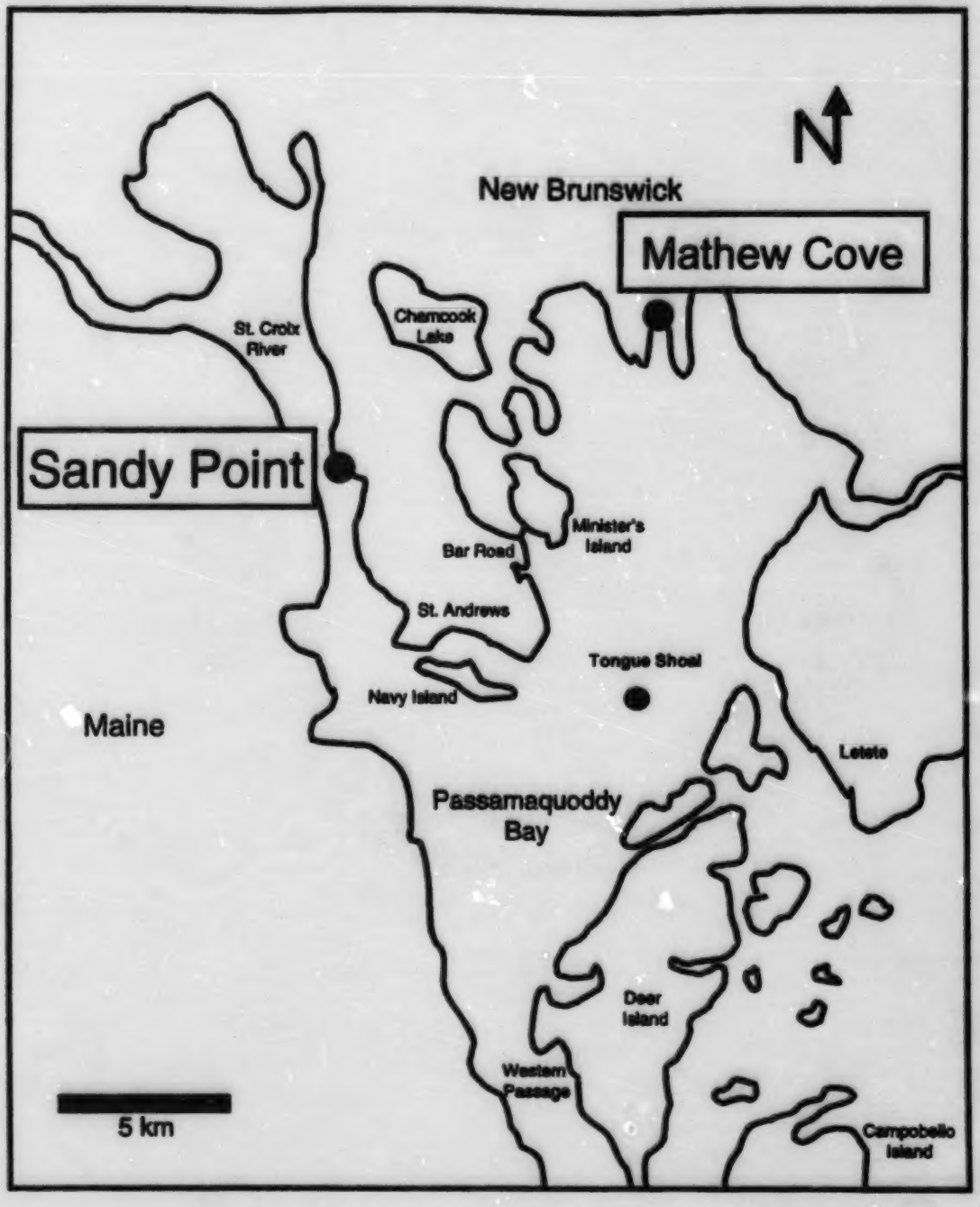


Fig. 2. Passamaquoddy Bay showing horse mussel sampling areas and the location of the growth experiments at Tongue Shoal.

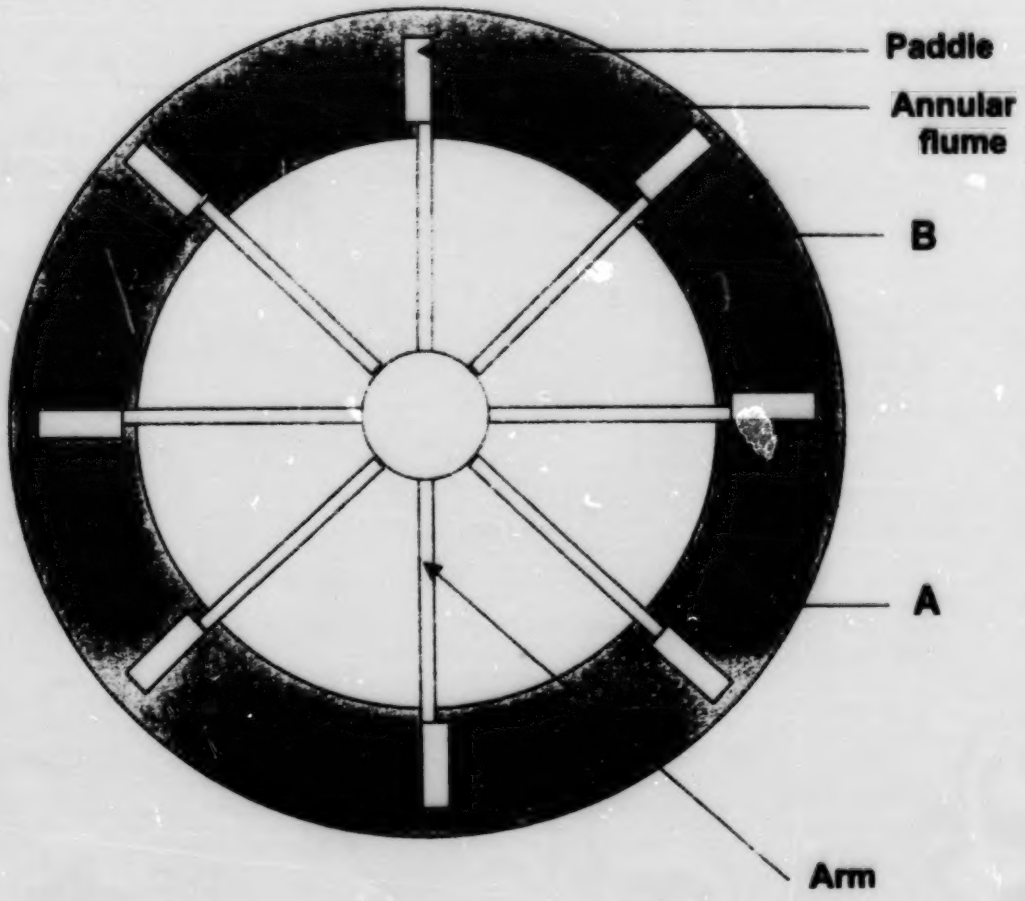


Fig. 3. Plan view of the annular flume.

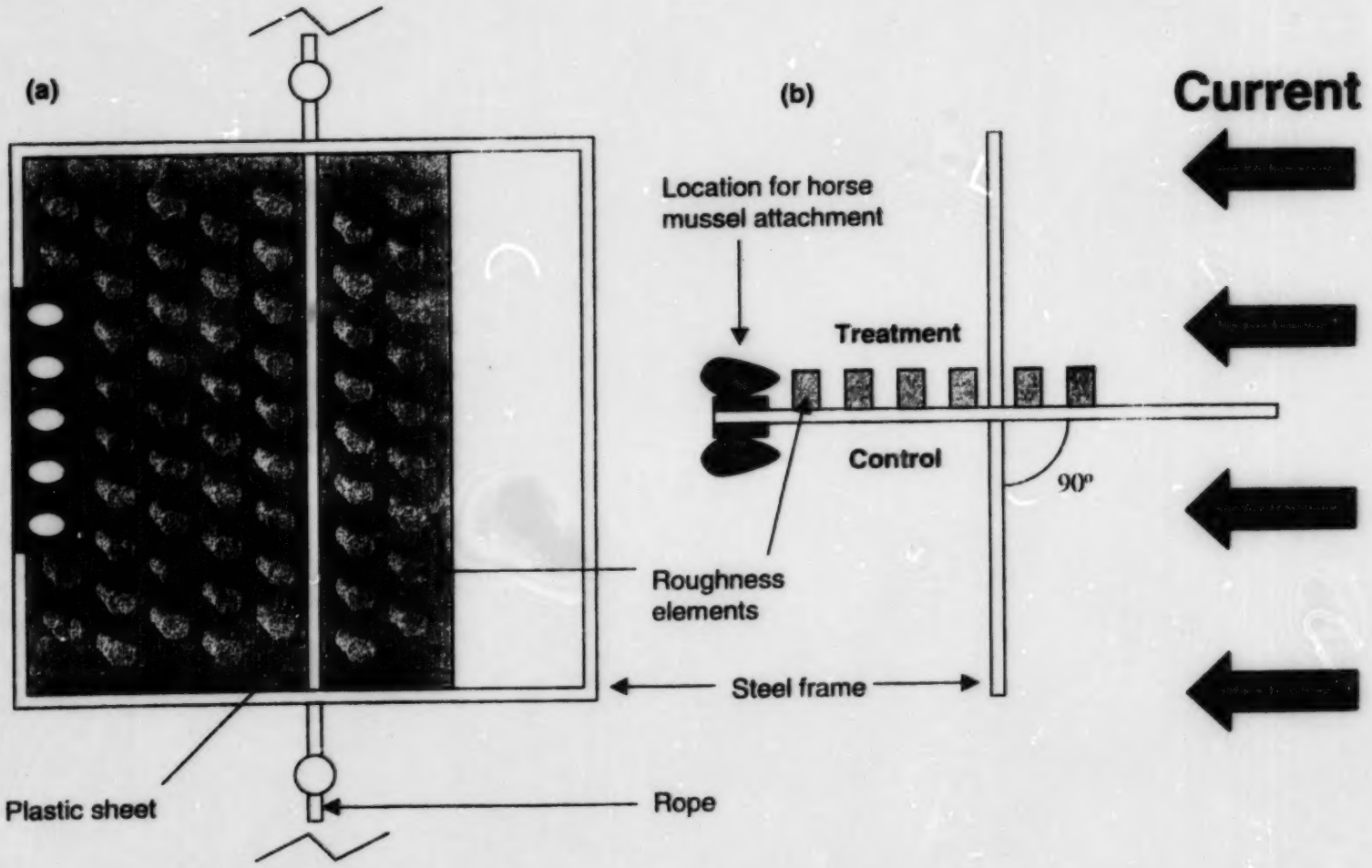


Fig. 4. Tidal vanes showing the downstream position of the five live horse mussels - (a) lateral view, (b) top view.

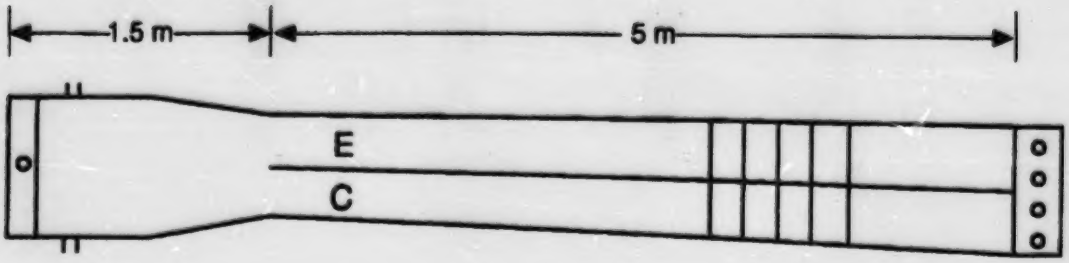


Fig. 5. Plan view of the outside flume. E = experimental channel and C = control channel. Five row positions of live mussels shown in each channel. Model mussels in E not shown (see text).

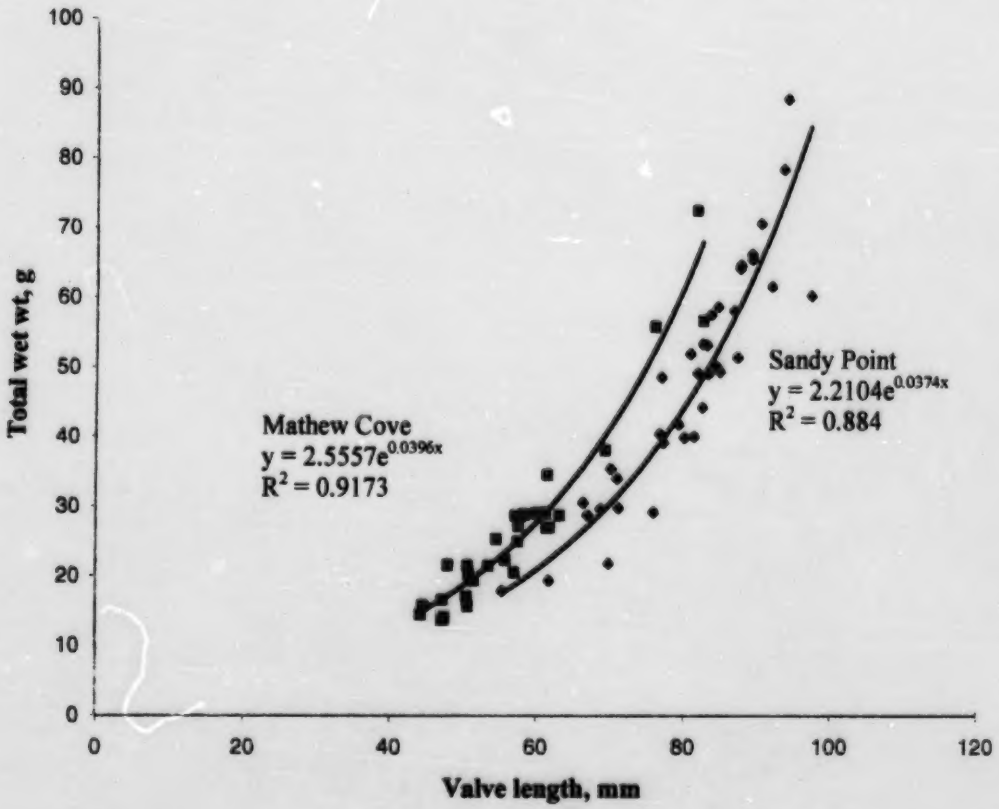


Fig. 6. Scatter diagram of total wet weight on valve length for horse mussels from Mathew Cove (■) and Sandy Point (◆).

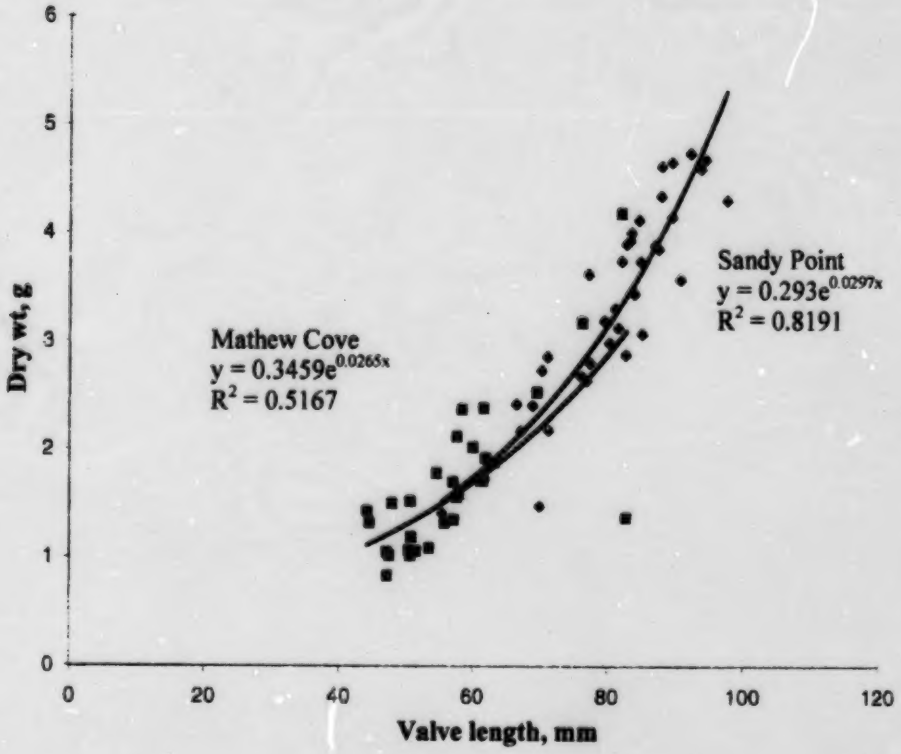


Fig. 7. Scatter diagram of dry weight on valve length for horse mussels. Symbols as in Fig. 6.

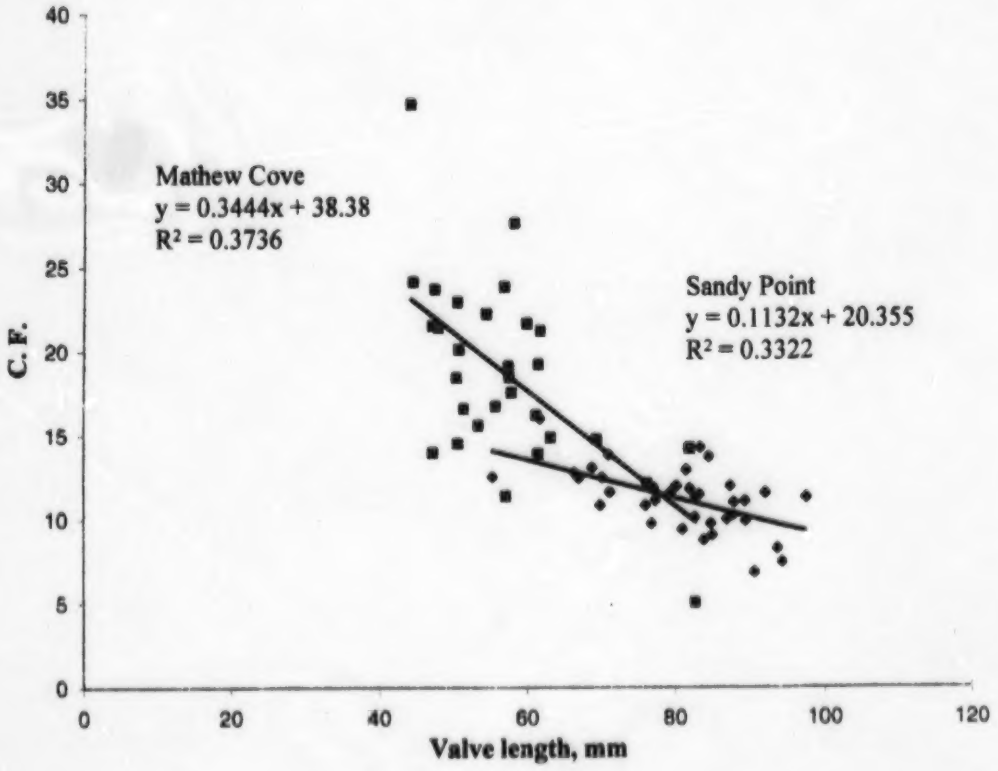


Fig. 8. Scatter diagram of condition factor, C.F., on valve length for horse mussels. Symbols as in Fig. 6.

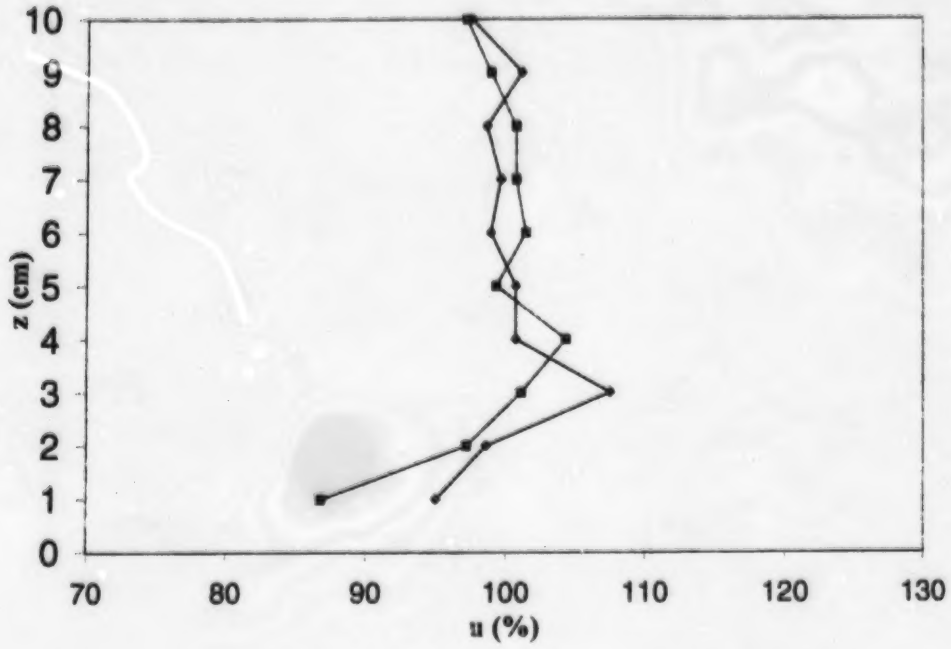


Fig. 9. Flow profiles at positions A (■) and B (◆) in the annular flume with model mussels absent, averaged over a period of 240 min. Flow setting = 7; bulk velocity = 22 cm s^{-1}.

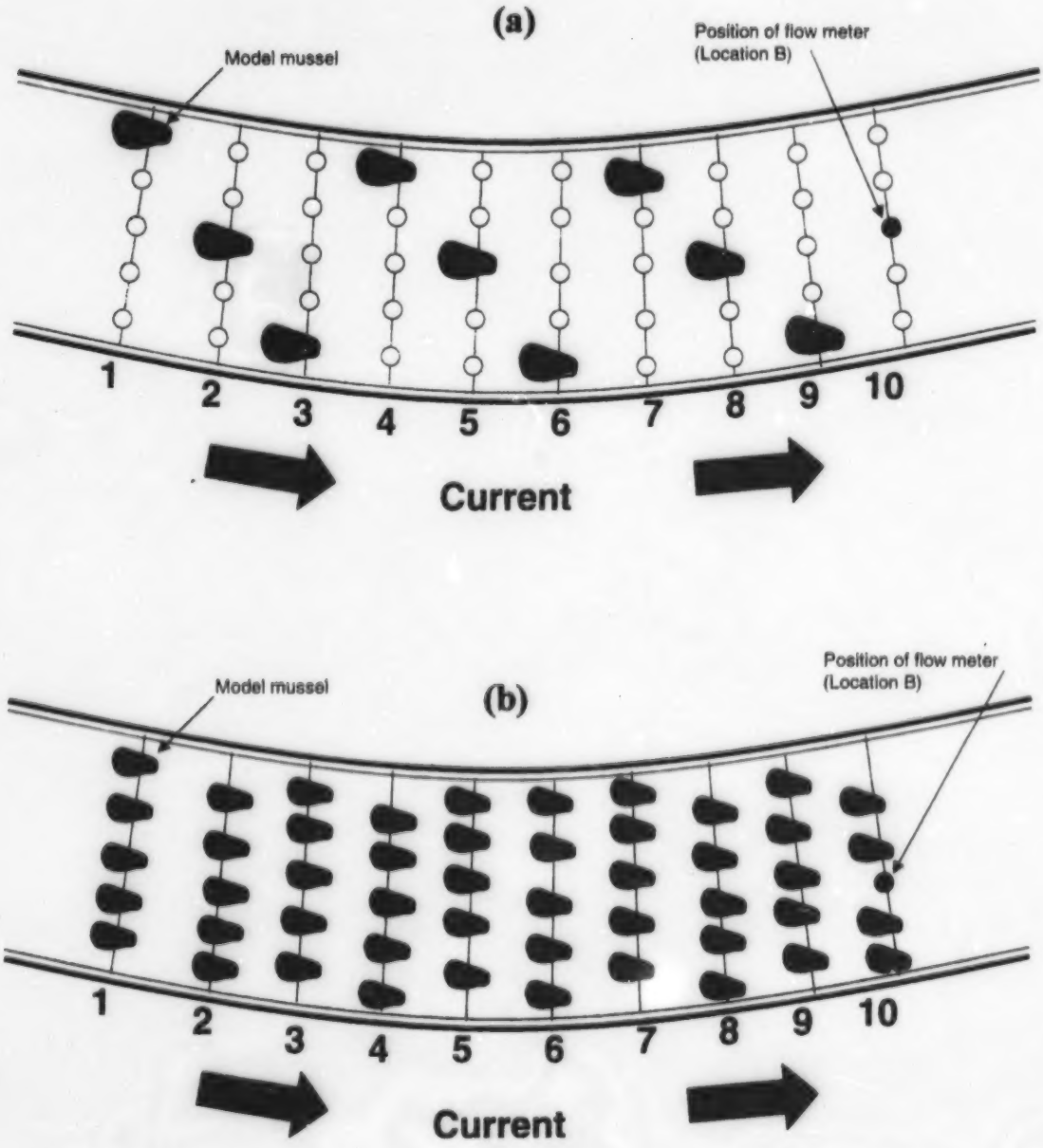


Fig. 10. Part of the annular flume floor to show the position of model mussels at two densities: (a) = 26 mussels m^2; (b) = 132 mussels m^2.

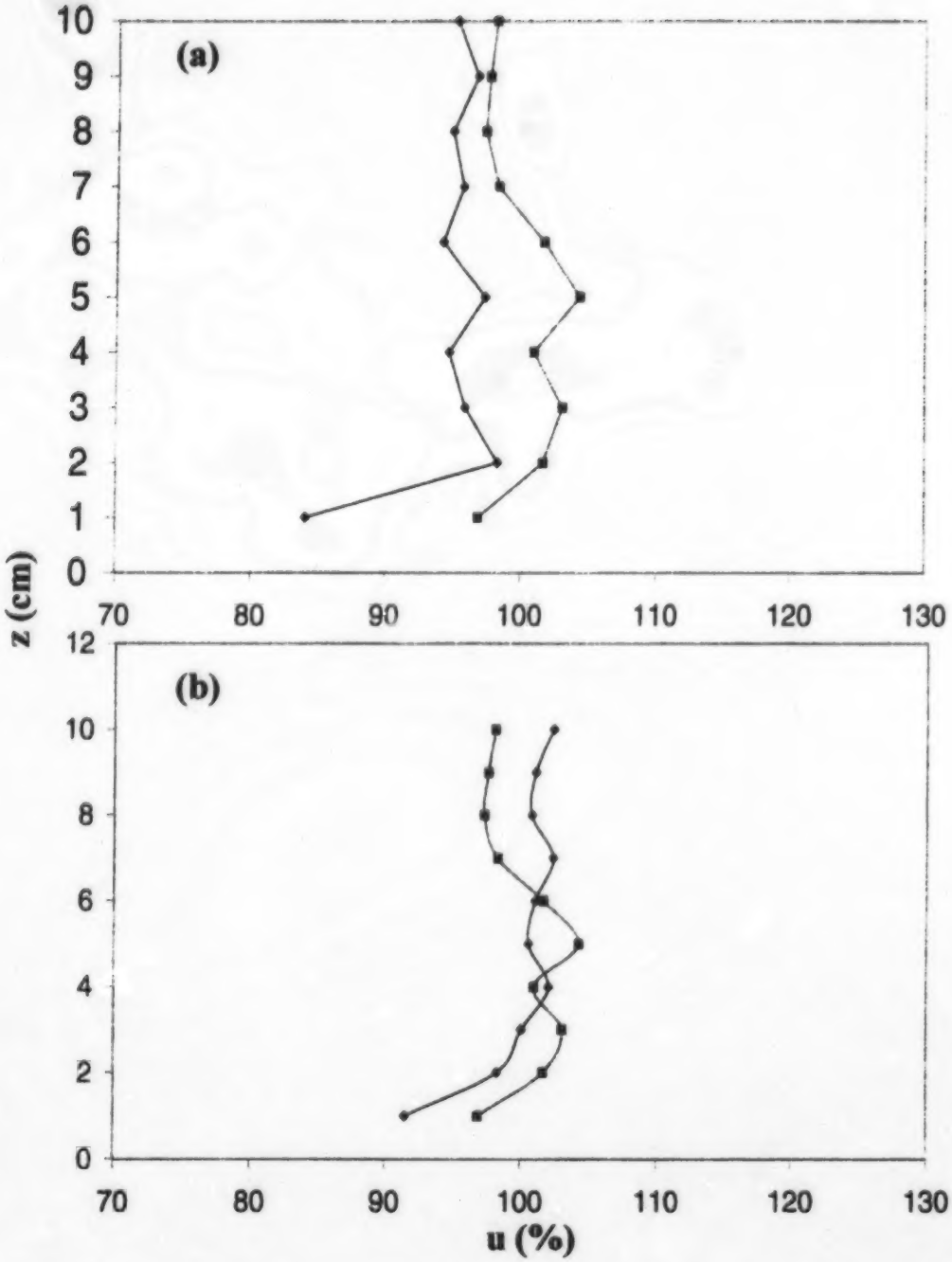


Fig. 11. Flow profiles at positions A and B (symbols as in Fig. 9) at (a) $\bar{u}$ = 26 cm s^{-1} and (b) $\bar{u}$ = 39 cm s^{-1}. Density = 26 mussels m^2; roughness height = 4.2 cm.

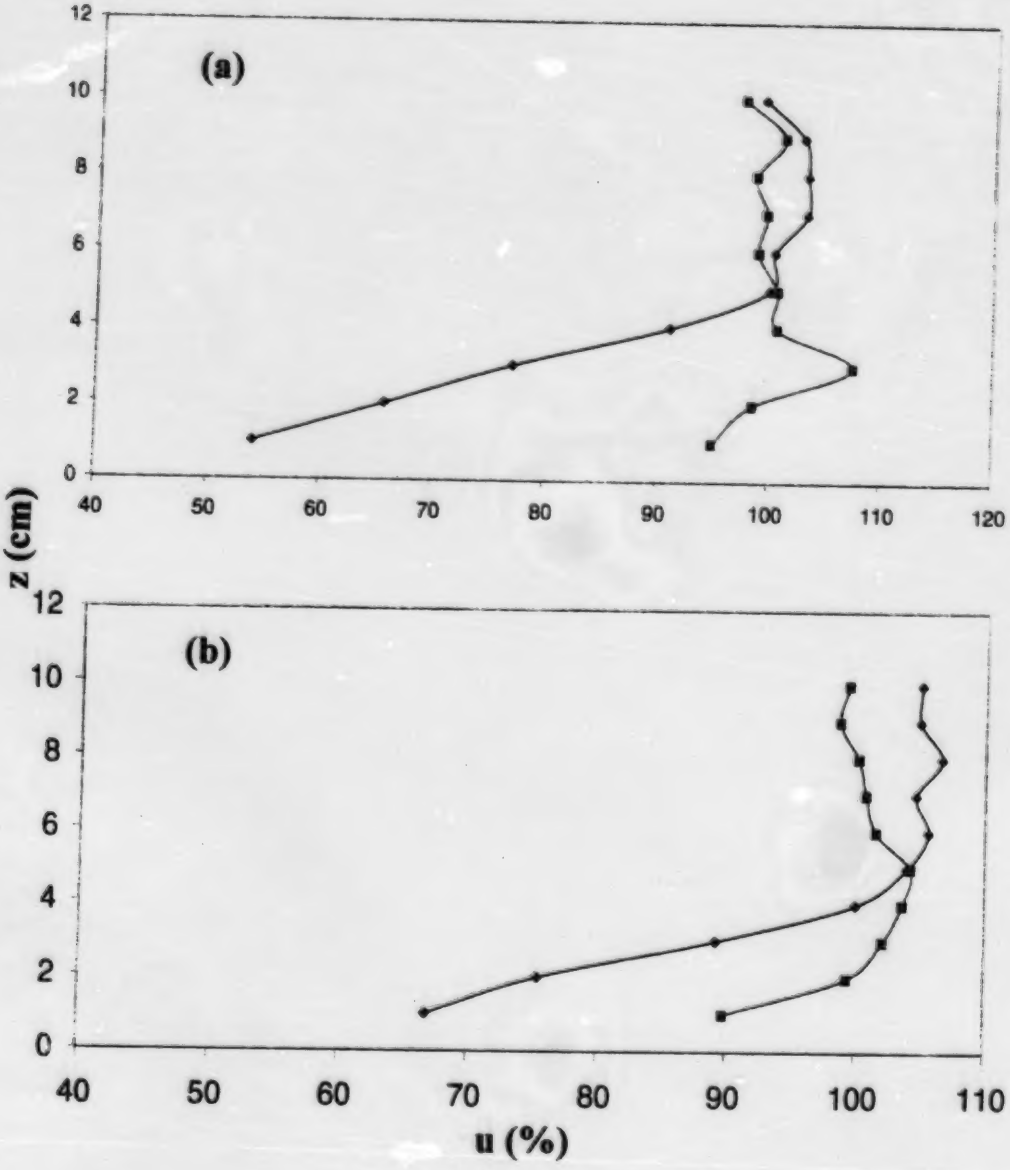


Fig. 12. Flow profiles at positions A and B (symbols as in Fig. 9) at (a) $\bar{u}$ = 20 cm s^{-1} and (b) $\bar{u}$ = 39 cm s^{-1}. Density = 132 mussels m^2; rows = 10.

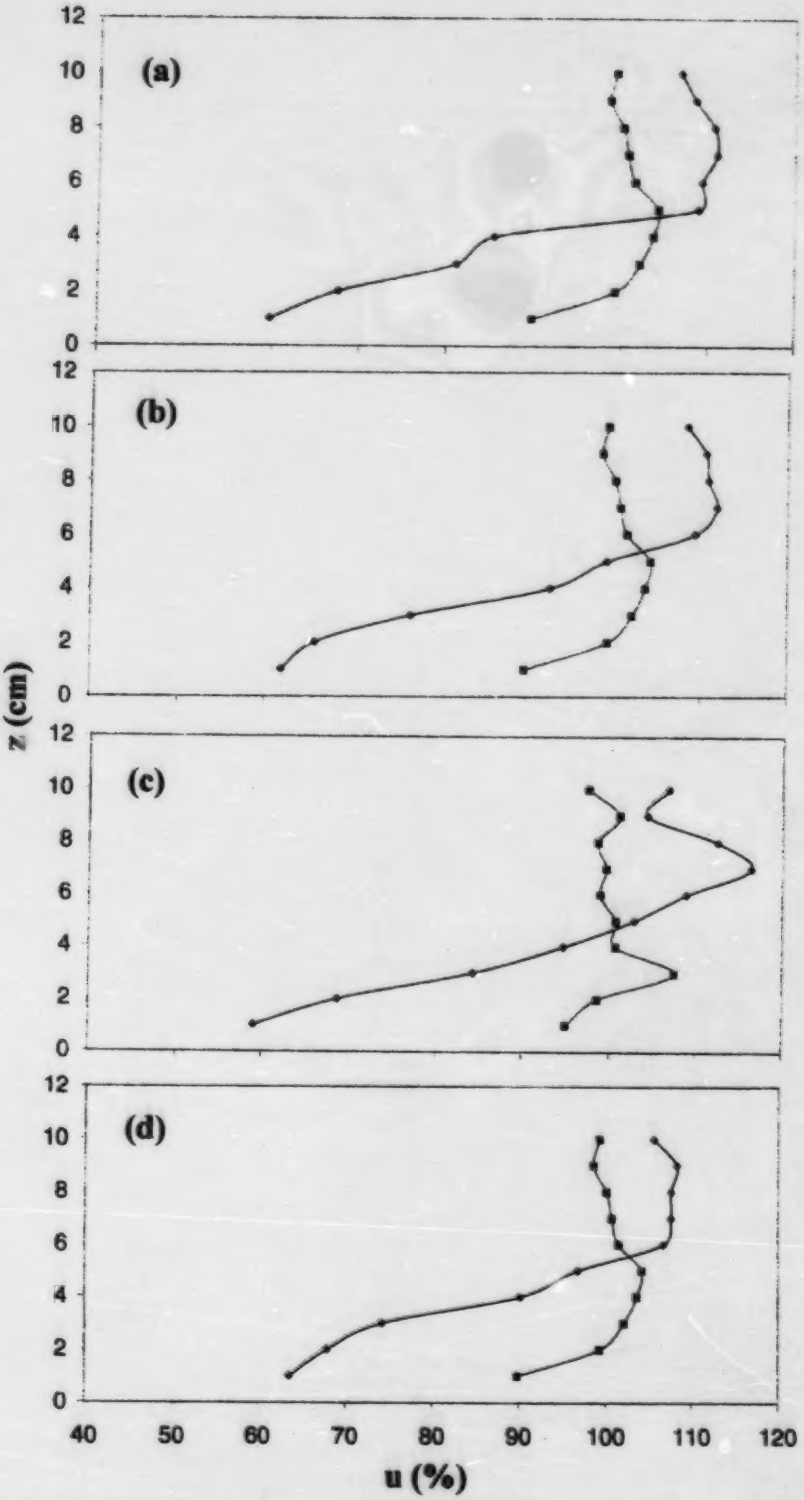


Fig. 13. Flow profiles at positions A and B with model mussels at the same density as in Fig. 12, but the number of rows present reduced: (a) 5 rows u = 20 cm s^{-1}; (b) 5 rows, u = 39 cm s^{-1}; (c) 7 rows, u = 20 cm s^{-1}; (d) 7 rows, u = 39 cm s^{-1}.

Appendix 1. Biometry of Sandy Point horse mussels collected on October 25, 1999, determined on March 6, 2000.

Number	Sex	Valve length, mm	Both valves weight, g	Tissue dry weight, g	CF
2591	M	89.51	41.69	4.14	9.94
2592	F	77.35	25.12	2.80	11.14
2593	M	61.77	10.77	1.72	16.02
2594	M	92.19	40.86	4.73	11.59
2595	F	86.99	38.71	3.88	10.03
2596	M	84.83	38.24	3.73	9.76
2597	M	90.72	52.12	3.57	6.85
2598	M	97.61	38.00	4.30	11.32
2599	M	87.94	41.81	4.61	11.03
2600	M	80.22	24.86	2.98	11.99
2601	M	67.06	17.39	2.17	12.46
2602	M	83.29	34.18	3.93	11.50
2603	F	82.67	28.37	2.87	10.13
2604	F	79.43	27.46	3.19	11.60
2605	M	71.05	20.61	2.86	13.85
2606	F	76.01	24.67	2.68	10.85
2607	F	93.81	55.47	4.59	8.28
2608	M	89.46	41.87	4.65	11.10
2609	M	66.46	18.90	2.41	12.78
2610	M	68.17	-	2.35	-
2611	M	93.23	-	5.16	-
2612	M	68.83	18.37	2.40	13.09
2614	M	84.60	29.97	4.12	13.73
2615	M	82.03	31.59	3.74	11.83
2616	M	77.12	30.35	3.62	11.91
2617	M	94.43	62.64	4.68	7.47
2618	F	87.86	42.19	4.34	10.28
2619	F	70.19	21.85	2.73	12.48
2620	M	85.08	33.85	3.07	9.06
2621	M	71.22	18.71	2.17	11.62
2622	M	83.91	39.18	3.43	8.76
2623	M	83.47	27.96	4.00	14.30
2624	M	82.73	34.39	3.89	11.32
2625	F	81.02	35.12	3.30	9.40
2626	M	87.48	32.06	3.85	12.00
2627	M	81.53	24.10	3.12	12.95
2628	M	55.35	11.21	1.41	12.54
2629	F	76.85	27.03	2.64	9.76
2630	M	69.93	13.59	1.47	10.85

Appendix 2. Biometry of Mathew Cove horse mussels collected on April 7, 2000 and determined in July 2000.

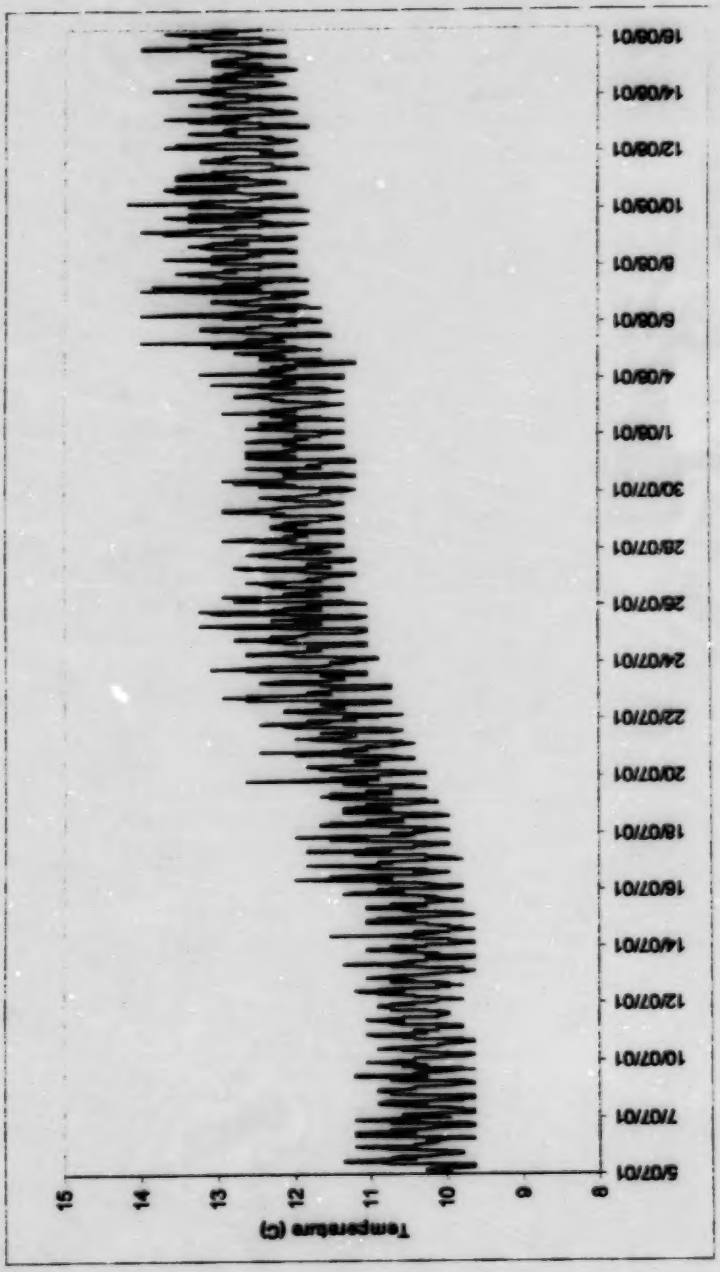
Number	Sex	Valve length, mm	Both valves weight, g	Tissue dry weight, g	C.F.
1	M	76.20	26.05	3.17	12.17
2	F	61.83	9.04	1.92	21.24
3	M	57.90	9.04	1.59	17.59
4	F	61.58	12.36	2.38	19.26
5	F	55.75	7.87	1.32	16.77
6	M	53.44	6.98	1.09	15.62
7	M	50.64	6.62	1.52	22.96
8	M	50.64	7.02	1.02	14.53
9	F	50.78	5.91	1.19	20.14
10	M	54.55	8.00	1.78	22.25
11	F	69.48	17.11	2.53	14.79
12	?	82.78	27.15	1.37	5.05
13	M	61.25	10.54	1.71	16.22
14	F	58.36	8.58	2.37	27.62
15	M	63.22	12.64	1.88	14.87
16	?	47.49	4.30	1.02	23.72
17	F	57.57	11.46	2.12	18.50
18	M	51.49	6.38	1.06	16.61
19	F	47.20	5.94	0.83	13.97
20	M	59.99	9.32	2.02	21.67
21	F	44.19	4.12	1.43	34.71
22	M	47.14	4.87	1.05	21.56
23	M	81.99	29.34	4.18	14.25
24	F	57.15	11.84	1.35	11.40
25	M	57.00	7.12	1.70	23.88
26	M	61.48	12.29	1.71	13.91
27	M	44.52	5.46	1.32	24.18
28	F	57.52	8.14	1.56	19.16
29	F	50.48	5.79	1.07	18.48
30	M	47.91	6.99	1.50	21.46

Appendix 3.Biometry of experimental mussels originating from Sandy Point(I) or Mathew Cove(II) in experiments which began on July 14, 2000 and terminated on October 5, 2000.

Experimental		Valve length, cm		Final weight, g		
number	Sex	Initial	Final	Both valves	Tissue dry	C.F.
Independent Control						
	F	9.89	9.98	77.70	8.2079	10.56
	M	8.92	9.09	66.90	5.3042	7.93
	F	8.79	8.82	58.35	5.2756	9.04
0/I	F	8.15	8.19	62.49	4.7271	7.56
	F	8.12	8.18	49.50	5.4565	11.02
	M	8.74	8.92	58.86	5.7076	9.70
	M	8.61	8.72	48.45	4.7246	9.75
0/II	M	7.47	7.56	49.02	2.6342	5.37
	M	8.48	8.77	61.21	3.9452	6.45
Roughness side mussels						
	M	9.06	9.08	60.03	4.8711	8.11
	F	9.45	9.52	74.03	3.9575	5.35
9/I	F	9.23	9.22	77.06	5.0637	6.57
	F	7.08	7.12	42.59	3.1922	7.50
	M	9.05	9.20	74.52	5.5215	7.41
	M	8.22	8.36	52.26	1.5664	3.00
9/II	F	6.86	6.90	38.19	1.9856	5.20
	M	6.45	6.41	25.75	2.2634	8.79
	F	9.57	9.56	111.47	5.7076	5.12
8/I	M	8.39	8.41	63.30	3.9966	6.31
	M	8.88	8.87	67.78	4.5000	6.64
	F	6.18	6.18	19.55	1.5929	8.15
8/II	F	7.83	7.90	45.95	2.7063	5.89
	M	6.50	6.55	27.92	2.1146	7.57
	M	8.28	8.32	55.16	4.5409	8.23
7/I	F	8.14	8.24	46.21	4.1259	8.93
	M	9.25	9.24	88.06	5.0127	5.69
	M	9.14	9.27	75.10	3.2553	4.33
7/II	F	5.59	5.62	14.52	0.9289	6.40
	M	6.32	6.34	31.06	2.0670	6.65

Appendix 3. (cont'd)

Experimental number	Sex	Valve length, cm		Final weight, g		C.F.
		Initial	Final	Both valves	Tissue dry	
Control side mussels						
	M	7.40	7.59	41.05	2.7374	6.67
	F	7.30	7.48	45.63	2.1063	4.62
9/I	M	8.07	8.08	48.09	3.6796	7.65
	M	7.62	7.65	38.67	3.1855	8.24
	M	7.18	7.37	36.29	2.8438	7.84
	M	5.04	5.02	14.24	1.0423	7.32
9/II	M	8.30	8.33	66.4	2.3869	3.59
	M	7.04	7.05	37.31	2.2125	5.93
	F	7.88	7.91	45.14	3.2081	7.11
8/I	F	8.24	8.26	66.87	3.8566	5.77
	M	8.12	8.14	52.53	4.0524	7.71
	M	9.23	9.24	94.63	4.3968	4.65
	F	5.93	5.97	20.16	1.5247	7.56
	F	7.10	7.12	39.8	2.1503	5.40
8/II	M	7.16	7.19	41.36	1.4570	3.52
	M	8.05	8.06	46.5	2.4576	5.29
	M	6.24	6.27	29.24	1.2413	4.25
	F	7.96	8.14	52.38	5.1564	9.84
7/I	F	8.20	8.25	73.41	6.0057	8.18
	M	8.42	8.39	58.27	4.2664	7.32
	F	8.57	8.61	55.1	4.6544	8.45
7/II	F	8.16	8.21	46.03	2.5648	5.57
	M	6.44	6.47	24.36	2.5169	10.33



Appendix 4. Seawater temperature record from Stow Away Tidbit set to record at half-hour intervals in the period July 5, 2001 to August 16, 2001.

Appendix 5. Current velocities in control (C) and experimental (E) flume channels at various positions along the flume working section (measured in meters from the inlet). Z= ht. above flume floor in cm. All measurements with probe #1330 are in cm/sec.

A. Flow profiling at 3.05 m., 5/7/2001

C3.05

	Z						
	0.8	1.8	2.8	3.8	4.8	5.8	6.8
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	3.59	4.14	4.69	5.23	5.78	6.32
	0	5.53	7.14	6.99	7.49	7.08	7.11
	0	5.68	6.75	7.11	7.02	7.23	7.46
	0	5.44	6.69	6.89	7.02	7.31	7.43
	0	5.32	6.84	7.02	6.96	6.99	7.70
Mean	0	3.86	4.46	4.57	4.68	4.74	4.91
Std. Dev.	0	1.44	2.11	2.18	2.25	2.29	2.45

E3.05

	Z						
	0.8	1.8	2.8	3.8	4.8	5.8	6.8
	0	3.15	2.82	2.78	2.82	2.78	2.80
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	2.61	2.61	2.61	2.61	2.61	2.61
	0	3.59	4.14	4.69	5.23	5.78	6.32
	0	4.24	4.75	5.62	6.21	6.00	6.51
	0	4.24	4.63	5.08	5.76	6.39	6.69
	0	4.15	4.60	5.56	6.30	6.27	6.57
	0	4.42	4.48	4.66	5.65	6.18	6.84
	0	4.12	4.72	5.29	5.65	6.51	6.48
Mean	0	3.58	3.80	4.15	4.54	4.77	5.00
Std. Dev.	0	0.76	0.99	1.33	1.65	1.84	2.02

B. Flow measurements (cm/sec) at fixed positions(m) and heights(cm) above the flume floor taken at various days during the experiment.

C2.00@0.8	Day 0	Day 6	Day 12	Day 26	Day 40
	6.38	8.40	6.05	5.78	5.72
	6.38	8.02	6.00	5.89	4.69
	6.05	8.07	5.18	3.70	6.10
	5.67	8.51	4.47	3.92	5.61
	5.83	8.02	4.79	5.39	5.50
	5.61	8.02	5.39	5.61	4.69
	5.50	7.25	5.67	5.07	5.18
	6.00	8.12	5.39	5.89	5.07
	5.23	7.63	6.16	6.16	4.79
	5.23	7.52	6.27	6.98	4.90
Mean	5.79	7.96	5.54	5.44	5.23
S.D	0.42	0.39	0.60	0.99	0.49

C2.00@6.8	Day 0	Day 6	Day 12	Day 26	Day 40
	8.07	11.51	7.69	8.29	8.12
	7.91	10.47	7.80	7.85	7.25
	6.71	10.47	8.34	7.91	8.29
	6.98	11.02	7.58	7.25	8.89
	7.20	10.15	7.31	8.89	8.29
	7.36	10.31	7.47	8.51	8.78
	7.91	10.42	7.25	8.07	9.22
	8.02	11.29	7.80	9.27	8.45
	7.58	9.44	8.07	8.56	8.12
	7.31	10.20	7.85	7.96	8.40
Mean	7.50	10.53	7.72	8.26	8.38
S.D	0.47	0.61	0.34	0.58	0.53

C2.94@0.8	Day 0	Day 6	Day 12	Day 26	Day 40
	4.47	6.21	4.30	4.69	3.87
	4.47	5.34	5.12	4.25	5.07
	4.19	5.34	4.58	4.03	4.58
	4.52	5.45	3.76	4.03	4.30
	4.85	4.85	5.23	3.87	4.08
	5.12	4.30	5.29	4.25	4.03
	4.79	5.50	4.74	3.87	4.36
	5.12	5.34	4.25	4.90	4.85
	4.69	5.61	4.25	4.41	4.79
	4.19	5.23	4.03	4.74	3.43
Mean	4.64	5.32	4.55	4.30	4.34
S.D	0.33	0.49	0.53	0.37	0.50

C2.94@6.8	Day 0	Day 6	Day 12	Day 26	Day 40
	7.36	9.82	7.85	7.91	7.74
	7.36	9.27	7.80	7.69	8.02
	7.63	10.04	7.52	8.07	7.63
	7.58	10.04	7.42	8.56	7.36
	7.20	10.69	8.07	8.40	7.63
	7.36	10.36	7.96	8.89	7.63
	6.81	9.98	8.12	8.56	8.45
	7.69	10.47	7.47	7.85	7.69
	7.47	10.15	7.91	7.63	7.52
	7.85	10.25	7.69	8.78	7.09
Mean	7.43	10.11	7.78	8.23	7.68
S.D	0.29	0.39	0.25	0.46	0.36

C3.94@0.8	Day 0	Day 6	Day 12	Day 26	Day 40
	3.27	6.21	4.79	5.39	3.16
	3.21	5.34	5.12	4.74	4.36
	2.83	5.34	4.90	4.41	3.43
	2.83	5.45	3.98	5.18	4.08
	3.59	4.85	4.63	4.74	3.32
	3.43	4.30	4.19	5.18	4.25
	2.94	5.50	5.72	4.79	3.59
	3.37	5.34	5.12	4.36	4.08
	3.16	5.61	5.12	5.07	3.70
	3.16	5.23	4.79	5.07	3.21
Mean	3.18	5.32	4.84	4.89	3.72
S.D	0.26	0.49	0.50	0.34	0.45

C3.94@6.8	Day 0	Day 6	Day 12	Day 26	Day 40
	7.69	9.82	8.56	8.56	7.52
	7.31	9.27	8.62	8.73	7.69
	7.14	10.04	8.51	9.00	7.58
	7.36	10.04	8.12	8.62	8.07
	8.23	10.69	8.02	8.12	7.25
	7.42	10.36	8.12	8.02	7.20
	8.12	9.98	8.23	8.62	7.96
	7.69	10.47	8.12	8.40	7.09
	8.07	10.15	8.67	7.69	7.03
	8.45	10.25	8.67	8.34	7.31
Mean	7.75	10.11	8.37	8.41	7.47
S.D	0.45	0.39	0.26	0.38	0.36

E2.00@ 0.8	Day 0	Day 6	Day 12	Day 26	Day 40
	4.85	5.72	4.90	4.52	3.27
	3.05	5.50	4.47	4.19	3.92
	4.90	4.85	4.85	3.92	4.03
	4.08	4.90	4.90	3.87	3.81
	3.98	5.01	4.85	3.10	4.79
	3.98	4.36	4.25	4.36	4.25
	4.41	5.12	5.12	3.32	4.41
	4.25	4.69	5.07	3.92	3.98
	4.58	5.39	5.50	4.30	4.47
	4.30	4.30	4.96	3.43	4.41
Mean	4.24	4.99	4.89	3.89	4.13
S.D	0.53	0.47	0.34	0.48	0.43

E2.00@6.8	Day 0	Day 6	Day 12	Day 26	Day 40
	6.10	6.92	6.54	6.00	6.21
	6.00	7.25	6.65	6.27	6.49
	6.00	7.14	6.54	6.38	6.10
	6.38	6.10	6.43	6.54	6.00
	5.89	6.32	6.54	6.16	6.05
	5.83	6.43	6.54	6.27	6.27
	6.00	6.81	6.76	6.38	5.45
	5.61	6.38	6.92	5.83	6.49
	6.00	6.60	6.60	6.32	6.10
	6.21	6.27	6.49	6.27	5.89
Mean	6.00	6.62	6.60	6.24	6.10
S.D	0.21	0.39	0.14	0.20	0.30

E2.94@0.8	Day 0	Day 6	Day 12	Day 26	Day 40
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0
Mean	0	0	0	0	0
S.D	0	0	0	0	0

E2.94@6.8	Day 0	Day 6	Day 12	Day 26	Day 40
	7.58	7.58	7.74	7.47	6.92
	7.03	7.85	7.74	6.98	6.98
	6.98	8.12	7.14	7.58	7.09
	6.87	7.63	7.52	7.25	6.71
	6.81	7.69	7.36	7.80	6.54
	7.14	7.63	7.69	7.52	6.71
	6.71	8.23	7.36	7.42	7.03
	6.87	8.23	7.03	7.31	6.71
	6.92	7.63	7.42	7.69	7.09
	6.81	7.69	7.36	7.63	6.43
Mean	6.97	7.83	7.44	7.46	6.82
S.D	0.25	0.27	0.24	0.24	0.23

E3.94@0.8	Day 0	Day 6	Day 12	Day 26	Day 40
	0	2.61	0	0	0
	0	2.66	0	0	0
	0	2.66	0	0	0
	0	2.94	0	0	0
	0	2.77	0	0	0
	0	2.61	0	0	0
	0	2.72	0	0	0
	0	2.72	0	0	0
	0	2.61	0	0	0
	0	2.99	0	0	0
Mean	0	2.73	0	0	0
S.D	0	0.14	0	0	0

E3.94@6.8	Day 0	Day 6	Day 12	Day 26	Day 40
	6.21	7.20	7.20	6.98	7.31
	6.27	6.92	7.42	7.42	7.03
	6.98	6.21	7.58	6.87	7.20
	6.54	6.16	7.52	6.98	6.32
	6.43	6.92	7.31	7.31	7.03
	6.54	6.43	7.25	6.92	6.71
	7.25	7.20	7.69	7.47	6.81
	6.43	7.42	7.20	6.92	7.36
	6.16	7.25	7.36	6.49	6.87
	6.05	7.14	7.58	7.09	6.81
Mean	6.49	6.89	7.41	7.04	6.95
S.D	0.37	0.45	0.18	0.29	0.31

Appendix 6. Biometry of Great Eastern Mussel Farms blue mussels on July 4, 2001, following harvest on June 28, 2001.

Mussel	Valve		Tissue weight in grams			
#	Length	Weight	Dish+dry	Dish	Dry wt.	C.F.
1	74.83	16.445	2.57847	0.98686	1.59610	9.70569
2	53.97	7.146	1.69220	0.99250	0.69970	9.79149
3	53.46	6.937	1.69390	0.99061	0.70329	10.13824
4	61.09	9.554	1.67086	0.98960	0.68126	7.13063
5	71.68	16.283	2.10674	0.99580	1.11094	6.82270
6	61.68	10.177	1.79352	0.99994	0.79358	7.79778
7	56.12	6.529	1.83382	0.99602	0.83780	12.83198
8	67.20	10.852	2.12531	0.99042	1.13489	10.45789
9	60.40	7.051	1.77746	0.98564	0.79182	11.22990
10	56.64	7.750	1.61862	0.99947	0.61915	7.98903
11	57.34	7.046	1.91855	0.99602	0.92253	13.09296
12	53.48	8.019	1.73431	0.99618	0.73813	9.20476
13	55.52	6.807	1.95172	0.99026	0.96146	14.12458
14	65.81	11.729	2.14655	0.99128	1.15527	9.84969
15	55.93	6.528	2.01770	0.99474	1.02296	15.67034
16	56.57	8.397	1.68982	0.99143	0.69839	8.31714
17	53.86	6.997	1.87378	0.99475	0.87903	12.56296
18	68.73	11.220	2.03906	1.01850	1.02056	9.09590
19	49.97	6.380	1.61555	0.99503	0.62052	9.72602
20	55.59	5.785	1.78870	0.99372	0.79498	13.74209
21	53.05	6.377	1.76451	0.99155	0.77296	12.12106
22	56.62	7.971	1.67113	0.99658	0.67455	8.46255
23	57.92	7.284	1.74090	0.99293	0.74797	10.26867
24	61.90	8.208	1.88389	0.98808	0.89581	10.91386
25	50.54	5.831	1.41606	0.98848	0.42758	7.33288

Appendix 7. Biometry of control blue mussels on August 15, 2001, experiment started July 5, 2001.

	Valve					Tissue Weight(g)							CF
	Lengths(mm)				$\frac{(L_{41}-L_0)\cdot 100}{L_0N}$	Wet			Dry			$\frac{(DW_{41}-DW_0)}{DW_0N}$	$\frac{100*DW_{41}}{V_{41}}$
Mussel #	Finish	Start	Growth	$Wt.(V_{41})$		Wet+dish	Dish	wet wt.	Dry+dish	$Dry\ Wt.(DW_{41})$	W_0		
2631	69.57	65.93	3.64	11.44941	0.13466	8.73075	0.98936	7.74139	2.23892	1.24956	1.060049	0.00436	10.914
32	72.76	72.55	0.21	14.15368	0.00706	8.4239	0.98978	7.43412	2.14014	1.15036	1.254015	-0.00202	8.1276
33	61.88	61.81	0.07	9.766385	0.00276	7.089	0.98413	6.10487	2.20409	1.21996	0.939333	0.007287	12.491
34	66.79	66.66	0.13	11.74761	0.00476	8.03948	0.98394	7.05554	2.0051	1.02116	1.081438	-0.00136	8.6925
35	59.56	59.35	0.21	8.761475	0.00863	6.80915	0.98275	5.8264	1.88151	0.89876	0.867255	0.000886	10.258
36	62.52	62.46	0.06	10.03191	0.00234	6.49189	0.9851	5.50679	1.81069	0.82559	0.958378	-0.00338	8.2296
37	72.89	72.82	0.07	14.26397	0.00234	9.42915	0.99201	8.43714	2.37308	1.38107	1.261926	0.002303	9.6822
38	60.11	59.88	0.23	8.97798	0.00937	5.85621	0.9906	4.86561	1.77965	0.78905	0.882784	-0.00259	8.7887
39	48.59	47.82	0.77	4.05147	0.03927	3.86243	0.99095	2.87148	1.44461	0.45366	0.529426	-0.00349	11.197
40	54.49	54.21	0.28	6.661785	0.0126	5.44035	0.99054	4.44981	1.84466	0.85412	0.716653	0.004678	12.821
41	55.95	55.86	0.09	7.33581	0.00393	5.3234	0.99204	4.33136	1.68822	0.69618	0.764998	-0.00219	9.4902
42	61.66	61.29	0.37	9.553965	0.01472	6.67186	0.99411	5.67775	1.96133	0.96722	0.924097	0.001138	10.124
43	56.33	56.08	0.25	7.42568	0.01087	5.8296	0.9925	4.8371	1.94917	0.95667	0.771444	0.005856	12.883
44	53.2	53.15	0.05	6.228775	0.00229	5.2039	0.99237	4.21153	1.66358	0.67121	0.685595	-0.00051	10.776
45	75.49	75.3	0.19	15.27705	0.00615	13.5061	0.98549	12.5207	3.0784	2.09291	1.33459	0.013859	13.7
46	56.79	56.64	0.15	7.65444	0.00646	5.6113	0.98652	4.62478	1.71157	0.72505	0.787852	-0.00194	9.4723
47	56.97	55.86	1.11	7.33581	0.04847	6.23216	0.99253	5.23963	1.91286	0.92033	0.764998	0.004952	12.546
48	61.18	60.84	0.34	9.37014	0.01363	6.38909	0.99314	5.39595	1.86758	0.87444	0.910912	-0.00098	9.3322
49	58.47	58.44	0.03	8.38974	0.00125	5.896	0.99262	4.90338	1.76245	0.76983	0.840592	-0.00205	9.1759
50	58.1	57.75	0.35	8.107875	0.01478	6.35255	0.98686	5.36569	1.92247	0.93561	0.820375	0.003426	11.54
51	55.92	55.77	0.15	7.299045	0.00656	3.85235	0.98342	2.86893	1.46433	0.48091	0.762361	-0.009	6.5887
52	61.3	61.19	0.11	9.513115	0.00438	6.54462	0.98381	5.56081	1.8704	0.88659	0.921167	-0.00092	9.3197
53	57.8	57.68	0.12	8.07928	0.00507	6.99328	0.98437	6.00891	1.81774	0.83337	0.818324	0.000448	10.315
54	49.4	47.92	1.48	4.09232	0.07533	3.75959	0.98986	2.76973	1.48847	0.49861	0.532356	-0.00155	12.184
55	64.03	63.85	0.18	10.59973	0.00688	7.63403	0.997	6.63703	2.19029	1.19329	0.999105	0.00474	11.258
$\bar{x}$=					0.01778						$\bar{x}$=	0.000878	10.396
S.D.=					0.02971						S.D.=	0.004573	1.7581

Legends:
L= Valve Length in mm.
DW= Total Dry Tissue Wt. mg.
WW= Wet Tissue Wt. In mg.
V= Total Wt. of both Valves in mg.
CF= Condition Factor of Brock and Wolowiez(1994)
N or (T_0-T_{41})= Duration of Experiment in days= 41
W_0= Wt from Init_L&W

Appendix 8. Biometry of experimental blue mussels on August 15, 2001, experiment started July5, 2001.

	Valve					Tissue Weight(g)							
	Lengths(mm)				$(L_{41}-L_0)\cdot 100$	Wet			Dry			$(DW_{41}-DW_0)$	CF $100*\frac{DW_{41}}{V41}$
Mussel #	Finish(L_{-1})	Start(L_0)	$L_{41}-L_0$	Wt.(shell)	L_0N	Wet+dish	Dish	wet wt.	Dry+dish	dry wt.	W_0	DW_0-N	
2656	63.16	63.12	0.04	10.30152	0.00155	6.83507	0.99234	5.84273	2.03532	1.04298	0.97772	0.00163	10.125
57	59.31	59.42	0	8.79007	0	5.65764	0.9919	4.66574	1.67284	0.68094	0.86931	-0.00529	7.7467
58	61.01	60.79	0.22	9.349715	0.00883	5.74634	0.98997	4.75637	1.82067	0.8307	0.90945	-0.00211	8.8848
59	65.19	64.84	0.35	11.00414	0.01317	8.04234	0.99056	7.05178	2.1846	1.19404	1.02811	0.00394	10.851
60	68.54	68.56	0	12.52376	0	9.21179	0.99017	8.22162	2.4606	1.47043	1.13711	0.00715	11.741
61	57.53	57.18	0.35	7.87503	0.01493	5.56505	0.9933	4.57175	1.75083	0.75753	0.80367	-0.0014	9.6194
62	56.37	56.14	0.23	7.45019	0.00999	5.49089	0.97184	4.51905	1.68212	0.71028	0.7732	-0.00198	9.5337
63	52.42	52.27	0.15	5.869295	0.007	3.78352	0.96968	2.81384	1.40253	0.43285	0.65981	-0.00839	7.3748
64	55.6	55.54	0.06	7.20509	0.00263	4.90922	0.97554	3.93368	1.63438	0.65884	0.75562	-0.00312	9.1441
65	62.11	61.9	0.21	9.80315	0.00827	6.26141	0.97982	5.28159	1.87963	0.89981	0.94197	-0.00109	9.1788
66	58.22	58.19	0.03	8.28353	0.00126	6.94918	0.97144	5.97774	1.96024	0.9888	0.83327	0.00455	11.937
67	64.88	64.59	0.29	10.90202	0.01095	8.16134	0.97685	7.18449	2.08454	1.10769	1.02079	0.00208	10.16
68	60.43	60.16	0.27	9.09236	0.01095	5.81225	0.99277	4.81948	1.7587	0.76593	0.89099	-0.00342	8.4239
69	62.91	62.87	0.04	10.1994	0.00155	7.42959	0.98762	6.44197	2.19478	1.20716	0.97039	0.00595	11.836
70	53.33	53.02	0.31	6.17567	0.01426	3.90174	0.98657	2.91517	1.41725	0.43068	0.68179	-0.00898	6.9738
71	52.76	52.67	0.09	6.032695	0.00417	5.52511	0.99329	4.53182	1.70244	0.70915	0.67153	0.00137	11.755
72	68.83	68.67	0.16	12.5687	0.00568	9.35826	0.9936	8.36466	2.35376	1.36016	1.14033	0.0047	10.822
73	59.09	58.95	0.14	8.598075	0.00579	6.7683	0.99144	5.77686	1.7786	0.78716	0.85554	-0.00195	9.1551
74	58.62	58.66	0	8.47961	0	4.7284	0.98303	3.74537	1.59389	0.61086	0.84704	-0.0068	7.2039
75	57.33	57.38	0	7.95673	0	5.2436	0.98218	4.26142	1.70262	0.72044	0.80953	-0.00268	9.0545
76	66.21	66.24	0	11.57604	0	7.93777	0.97655	6.96122	1.99736	1.02081	1.06913	-0.0011	8.8183
77	59.08	59.01	0.07	8.622585	0.00289	6.52487	0.9729	5.55197	1.82891	0.85601	0.85729	-3.7E-05	9.9275
78	60.71	60.67	0.04	9.300695	0.00161	6.76972	0.97831	5.79141	1.95681	0.9785	0.90593	0.00195	10.521
79	53.17	52.82	0.35	6.09397	0.01616	5.30453	0.9793	4.32523	1.74918	0.76988	0.67593	0.00339	12.633
80	58.17	58.18	0	8.28353	0	7.09095	0.97988	6.11107	1.85946	0.87958	0.83297	0.00136	10.618
$\bar{x}$=					0.00567							-0.00041	9.7615
S.D.=					0.0054							0.00427	1.5585

Legends:

L= Valve Length in mm.
DW= Total Dry Tissue Wt. mg.
WW= Wet Tissue Wt. In mg.
V= Total Wt. of both Valves in mg.

CF= Condition Factor of Brock and Wolowiez(1994)
N or (T_0-T_{41})= Duration of Experiment in days= 41
W_0= Wt. From Init_L&W